Abstract—The Porto University testbed developed under the SUNRISE FP7 project is described along with its intended uses for experimentation with Future Internet technologies. First, the SUNRISE project and the FIRE initiative are briefly described as background information for the presentation of the testbed. Second, the key components of the testbed are presented with reference to ocean-going autonomous vehicles, static sensor and communication nodes, and underlying software tool chain. Third, the integration of the testbed in a federation of five underwater communication networks, based on pilot infrastructure designed, built and deployed by SUNRISE partners is discussed in the context of experimentation of Future Internet technologies.

I. INTRODUCTION

This paper describes the Porto testbed of ocean-going vehicles and static sensor and communications nodes developed and implemented in the context of the SUNRISE Project [1].

The Porto testbed is targeted at supporting collaborative evaluation and testing of network behavior and control of underwater and surface vehicles evolving in inter-operated, and possibly intermittent, underwater and wireless communication networks. The testbed supports both local and remote Internet access to enable collaborative experimentation and testing from anywhere in the world.

The testbed is deployed in an area encircling the Port of Leixões (exposed to the outflow of the Douro river, which is located 5 km South of the harbor). Leixões is one of the most important seaports in Portugal. Its modern infrastructure is continuously facing new challenges arising from the selective collection of waste, environmental and structural inspections, minimisation of the environmental impact deriving from commodity handling, environmental certification, cleaning of the wharf area of the port, leveling of the final stretch of the River Leça, monitoring security threats, monitoring of the navigation channel, and development of advanced capabilities for intervention in the case of disasters.

The testbed supports testing and evaluation of new systems. It also supports harbor operations, such as environmental monitoring, sea-bottom mapping, and operations in the context of maritime incidents. This testbed is a major asset for a harbor that is embedded in the city.

The testbed was experimentally deployed in July 2014 and was possible because of a long standing cooperation between Porto University and the Porto harbor authority, the Portuguese Navy and the Portuguese Task Force for the Extension of the continental Shelf. It is also aligned with the Polo do Mar (Porto University’s Sea Center) strategic initiative undertaken by Porto University. The Polo do Mar facilities will be inaugurated in 2014 and will provide additional support and access to the testbed. Support vessels from the Porto harbor provide access to all the components of the testbed. The testbed builds on the experience of the Laboratório de Sistemas e Tecnologia Subaquática (Underwater Systems and Technology Laboratory, LSTS) in the deployment of unmanned air, surface and underwater vehicles in innovative operations in the Atlantic and Pacific oceans, and also in the Mediterranean and Adriatic seas.

All SUNRISE testbeds are connected to the Internet via a centralized OpenVPN [2] server. This server allows users to effectively control vehicles and assets using the Internet Protocol (IP) suite. Data collected by underwater vehicles can be monitored in quasi real-time using acoustic links and downloaded after the experiment is completed using radio
links. At any stage of an experiment the user can change operational parameters and control the trajectory of vehicles.

Some possible applications of the Porto testbed are:

1) Evaluation of Medium Access Control (MAC), routing and cross-layer protocols using underwater robots;
2) Environmental data collection using multiple vehicles;
3) Underwater localization and time synchronization;
4) Control algorithm evaluation with underwater robots.

The paper is organized as follows. Section II introduces an overview of the SUNRISE FP7 project. Section III presents the key components of the testbed. Section IV discusses integration in the SUNRISE federation of testbeds. Section V presents the conclusions.

II. SUNRISE FP7 PROJECT: AN OVERVIEW

The SUNRISE FP7 project (2013-2017) is led by the University of Rome “La Sapienza” (Italy) with partners from Portugal (LSTS), Italy (NATO Science & Technology Organization - Centre for Maritime Research and Experimentation and NexSe), Germany (EvoLogics), Netherlands (University of Twente), Turkey (SUASIS), and the United States (University at Buffalo). The SUNRISE objectives are to develop:

- Five federated underwater communication networks, based on pilot infrastructure already designed, built and deployed by consortium partners, in diverse environments (Mediterranean, Ocean, Black Sea, Lakes, Canals), web-accessible and interfaced with existing FIRE facilities to experiment with Future Internet technologies;
- A software-defined open-architecture modem and protocol stack that will empower open collaborative developments;
- Standard platforms for simulation, emulation and replay testing to estimate underwater communication networks at a fraction of time, cost, complexity of current at-sea experiments, validated by tests conducted on the SUNRISE networks over a variety of applications and environments;
- A user-friendly interface for diverse users to interact with SUNRISE systems in order to conduct trials and benefit from databases of underwater Internet of Things (IoT) performance data gathered over long periods from the SUNRISE infrastructure.

SUNRISE will also significantly exceed and enhance the features supported by current underwater test-beds and installations by exploring, implementing and developing a novel paradigm of software defined modem and software defined communication stack, which allows experimentation with novel physical layer techniques, novel cross-layer optimized and adaptive underwater communication protocols and, novel schemes for underwater devices cooperation. SUNRISE facilities will also provide large scale testing infrastructures (with respect to the expected size of underwater networks and to the size of current deployments), and a level of heterogeneity in terms of assets involved, marine environments and applications, that which is not available as of today. The SUNRISE developed tool chain will also reduce time to market and time to experiment considerably and will provide a key tool to support optimization of solutions, code generation, programmability and re-programmability of underwater deployments. Finally, SUNRISE-GATE will provide an effective tool for application and service development, incorporating and integrating heterogeneous flows of information available in different remote systems and over the Internet in a transparent way, as well as allowing the incorporation of models of underwater phenomena of interest, elaborated by scientists, for context awareness and to provide efficient decision making support in different application domains.

SUNRISE directly addresses FIRE objectives by combining technology with novel paradigms in new, open experimental facilities, integrating physical systems with software development into the Internet of Underwater Things. It is the first project that develops this concept, based on joint research performed in the partners in the last few years. SUNRISE will also provide a way to select Internet of Underwater Things standards based on objective measures of performance, strengthening its facilities as more sites are added in the future as a result of the two envisioned open calls.

III. KEY COMPONENTS

The key components of the Porto testbed are described next.

A. AUVs

Up to 6 units of the award–winning Light Autonomous Underwater Vehicle (LAUV) [3], depicted in Figure 1, are available in several configurations. The LAUV is a torpedo shaped vehicle with one propeller and 4 control fins. The maximum operating depth is 100 m. The maximum speed is 2 m/s, and the maximum distance that can be traveled on a battery charge is over 100 km in some configurations. The LAUV class vehicles are equipped with several types of side-scan sonars (Imagenex, Marine Sonics, and Edgetech), multibeam sonars (Imagenex), acoustic modems (EvoLogics and WHOI Micro-modem), environmental sensors (conductivity, temperature, salinity, fluorescence, velocity of sound, turbidity, hydrocarbons, dissolved oxygen), video cameras, imaging sonars (Blueview P900) and profiling sonars (Imagenex) for obstacle avoidance. In addition, all of these vehicles are equipped with Global Navigation Satellite System (GNSS) receivers and General Packet Radio Service (GPRS), Wi-Fi, and Iridium Short Burst Data (SBD) transceivers. Two navigation suites are available for the LAUV class vehicles: 1) Long baseline navigation, which relies on pre-positioned external beacons; and 2) Inertial navigation, which relies on tactical grade Inertial Measurement Units (Honeywell 1700) and Doppler Velocity Log (Linkquest), thus making the vehicle independent of external navigation aids.

B. Acoustic Localization Systems

External narrow band transponders (Teledyne Benthos) and acoustic modems (WHOI Micro-modem and EvoLogics S2C) are available at fixed positions to aid AUV navigation.
C. Autonomous Surface Vehicles (ASVs)

Two types of ASV are available. First, the ASV version of the LAUV vehicle. This is basically a LAUV with two additional hulls for stability and a mast that is used for mounting antennas and video cameras. Second, the Swordfish catamaran [4]. These vehicles can be used as mobile underwater-wireless communication gateways.

A photograph of Swordfish catamaran is given in Figure 2. This is a 4.5 m long catamaran based platform equipped with computers, electric motors and sensor systems mounted on the twin hulls for autonomous operation. The maximum speed is 4 m/s and the endurance is in the order of 6 hours. Swordfish is equipped with one GNSS and AIS receivers, Wi-Fi, GPRS, and Iridium SBD transceivers, several types of side-scan sonars (Tritech,Imagenex, Marine Sonics), environmental sensors (CTD, chlorophyll, velocity of sound, backscatter), video cameras, and imaging sonar (Blueview P900). Navigation is based on a Global Positioning System (GPS) compass and on an Inertial Measurement Unit (Honeywell HG1700).

D. Remotely operated vehicle (ROV)

The Adamastor ROV weighs around 90 kg and is equipped with 5 Seaeye SI-MCT01 thrusters. It has advanced thrust and power control for operations at sea, and can be used for underwater inspection and intervention. The maximum operating depth of this ROV is 200 m and it’s equipped with a video camera and a two-degrees-of-freedom robotic arm. A photograph of the vehicle is given in Figure 3.

E. Manta Gateways

Up to 6 units of the Manta gateway are available. The Manta Gateway is a portable centralised communication hub supporting several types of wireless and acoustic networks. The system is capable of transparently route data between heterogeneous network links, balancing bandwidth and range. Additionally the device is capable of providing information about the localization of underwater vehicles and narrow band acoustic transponders. The gateway can be mounted on buoys. It supports up to three 12V power-over-Ethernet radios connected at the same time and provides 18 hours of autonomy (with two radios). In the Porto testbed some units are externally powered. A photograph of several Manta gateways is given in Figure 4.

F. Buoys and Moored Sensors

Up to 6 buoys are available for mounting communication gateways, acoustic modems, and environmental sensors.

G. Shoreside Control Station

The shoreside control station is comprised of two systems, one installed on an industrial container near the operations area, and the other installed in an office inside the marina facilities. The latter is connected to the Internet via Ethernet and connected to the industrial container via a 802.11n link. This topology allows all systems in the operations area to be reachable and controllable over the Internet.


H. Software Toolchain

The testbed is deployed with the help of the Neptus-IMC-DUNE software toolchain [5]. Neptus is a distributed command, control, communications and intelligence framework for operations with networked vehicles, systems, and human operators. Neptus supports all the phases of a mission life cycle: world representation; planning; simulation; and, execution and post-mission analysis. IMC is a communications protocol that defines a common control message set understood by all types of LSTS nodes (vehicles, consoles or sensors) in networked environments. This provides for standard coupling of heterogeneous components in terms of data interchange. DUNE is the on-board software of all LSTS vehicles. It is used to write generic embedded software for control, navigation, and interaction with sensors and actuators. It provides an operating system and architecture independent C++ programming environment for writing efficient real-time reactive tasks in modular fashion. Additionally, the LSTS toolchain is integrated with the SUNSET [6] software framework.

IV. SUNRISE Federation of Testbeds

The SUNRISE federation of underwater testing infrastructures will pioneer fast development, prototyping and testing of novel European technologies, applications and services for marine and ocean monitoring, exploitation and, control. This motivates the added value of a federation of testing infrastructures spanning all the different underwater environments (Ocean, Mediterranean, Black Sea; shallow water and deep water; Lake and Canals monitoring) which are representative of the typical different water environments. Key features of the federation are enumerated next:

- Support different application domains;
- Enable testing of solutions for all the system components and at all the different layers of the system in a very natural way;
- Have a level of heterogeneity (in terms of supported sensors and underwater platforms, communications technologies, and marine environment - thus acoustic channel features) which allows the assessment and performance evaluation of the proposed IoT systems in the whole spectrum of relevant marine domains and applications;
- Allow testing of solutions for static networks, mobile networks, hybrid network integrating underwater and terrestrial monitoring systems (e.g., AUVs and flying drones);
- Support scalability, allowing the integration of additional platforms and devices, made available by partners or by third parties, in an easy and natural way;
- Support security, privacy and trust by providing an environment in which solutions for underwater security can also be developed and tested;
- Expose Underwater Acoustic Sensor Network Internet of Things islands as an element of the Future Internet, thus allowing the integration of heterogeneous information for value added applications and services.

V. CONCLUSION

The Internet of the Future will be significantly different from what is available today. This is because technological trends and projected developments of capabilities will entail a paradigm shift into system(s) of systems distributed all over the world. New concepts will revolve around interactions, teaming, persistence, services, network behavior, and dynamic reconfiguration. These will, in turn, pose new organizational and legal challenges to the society, which is still far from understanding their potential. Experimentation and evaluation of systems and technologies is needed to address these challenges.

The federation of five testbeds built and deployed by SUNRISE partners will allow unprecedented experimentation of new tools and technologies and will enable the realization of potential of some aspects of the Internet of the Future. The Porto University testbed will play a major role in this aspect. This is because of the seamless integration of web-accessible (and interfaced with existing FIRE facilities) unmanned autonomous ocean going vehicles, static communication nodes and remote control centers.

The implications of the Porto University testbed developments for the Internet of the Future are endless. These will be especially important for ocean observation, maritime surveillance and security. For example, a network of national observatories is being coordinated to provide ocean data for the Global Ocean Observing System (GOOS) [7]. Many observatories are surface or seafloor moorings with sensor arrays. Discussions have been underway to further develop Integrated Ocean Observing Systems (IOOS) which also include propeller-driven AUVs, ASVs, and Unmanned Air Vehicle Systems (UAS). This entails being able to command and control networks of manned and unmanned vessels which, in turn, may form ad-hoc communication networks allowing extended and cost-effective communications coverage. Observe that presently most systems at sea lack basic networking capabilities.
REFERENCES


